SOME EFFECTS OF VARYING AMOUNTS OF NITROGEN ON THE GROWTH OF TULIP POPLAR SEEDLINGS.*

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INTRODUCTION.

While many studies have been made on both the more general and the detailed effects of different amounts of available nitrogen on several horticultural and crop plants, few investigators have given much consideration to comparable problems relative to forest tree species. It is known, however, that plants in general under these conditions make somewhat similar responses in leaf color and vegetative organs, but that the more detailed behavior varies widely. The present study began with one year old seedlings of tulip poplar (*Liriodendron tulipifera*, L.). Stock of this important forest tree species is commonly produced in forest nurseries for reforestation projects in the eastern states. As the survival of transplants is often largely dependent upon the quality of stock itself, it seems that a knowledge of the behavior of a particular species grown under different nitrogen conditions is essential to production of desirable seedlings.

Hesselman (1917) in his study of the subordinate vegetation associated with regenerating coniferous forests has listed two general groups of plants based on the form of accumulated nitrogen compounds found in the tissues. Those which contain nitrate nitrogen are called "nitratophilous plants," even though they give nitrate tests only when grown in soils high in nitrogen. The other group includes those species which do not show an accumulation of nitrate nitrogen under similar conditions.

Schimper (1890) found quite inconsiderable amounts of nitrate nitrogen in the tissues of tree seedlings grown on compost soil very rich in nitrates. From analyses made on various parts of apple trees on plots which had been supplied with varying quantities of nitrate nitrogen, Gourley (1915) found

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no correlation between the amounts of nitrate nitrogen in the tissues and the amounts added to the soil. In all cases, the nitrate nitrogen present in the trees was almost negligible.

Busgen (1917) quotes Ebermayer (1882) as having found the woody cylinder poor in nitrogen, 0.17 percent of its dry weight. Fallen leaves of beech, spruce, and pine contained 1.34, 1.06, and 0.91 percent respectively of nitrogen. Dried green leaves of oak and elm at the end of July showed 2.30 and 1.87 percent nitrogen. He estimated that the nitrogen requirement per acre per year for the beech forest is 45.5 pounds. According to Passler (1893), most of the nitrogen absorbed by roots accumulates in the leaves, only one-fourth to one-fifth is stored in the stem. Gaumann (1928) found 0.07 and 0.08 percent protein respectively for the heartwood and sapwood of *Abies pectinata* and 0.05 and 0.06 percent protein for the heartwood and sapwood of *Picea excelsa*.

According to Falkenstein (1913), Hesselman (1917), Weidmann (1924) and others, nitrate nitrogen seems to be the best source of nitrogen for forest trees. The "more exacting" broad-leaved tree species, especially the young growths, respond well to nitrification in the soil. Wherry (1926) reports studies in Finnish forests by Ilvessalo (1923) which show definite correlations between the increment of the trees and nitrogen content of the soil. Fertilizer investigations at the Savenac forest nursery, Haugen, Montana, by Wahlenberg (1930) showed that seedlings given a heavy application of a nitrogenous compost were twice as tall and had much thicker stems than plants in check plots.

From investigations on tomato plants, Kraus and Kraybill (1918) described the relationship between the amount of available nitrogen and the development of shoot and roots, that is, a high nitrogen supply is associated with a greater shoot than root growth, and a low nitrogen supply is associated with a greater root than shoot growth. Wahlenberg's work also shows a shoot-root ratio of 2.2 for heavily fertilized Englemann spruce seedlings, based on oven-dry weights, as against 1.75 for unfertilized seedlings. Chandler (1919) in a study of peach trees, concluded that the addition of nitrates to the soil is associated with a greater development of top than roots.

Wahlenberg observed that many thrifty, dominant Engelmann spruce seedlings in heavily treated beds develop yellowish tips on mature needles quite unlike the yellowishness of needles developed in poor soil. Reid (1930) observed mottling in squash leaves after extra nitrogen was supplied.

The purpose of this paper is to describe the effects of different quantities of ammonium nitrate upon the distribution of nitrogen compounds and growth responses in tulip poplar seedlings under a given environment.

PRODUCTION OF EXPERIMENTAL MATERIAL.

One year old tulip poplar seedlings were used in these experiments. They were selected from a lot obtained late in November, 1929, from the state forest nursery near Marietta, Ohio. The selected seedlings were placed in cold frames where they remained until March 15, on which date they were potted in one-gallon, white, glazed, earthenware jars.

TABLE I.

AMOUNT OF AMMONIUM NITRATE ADDED PER JAR IN EACH UNIT OF FIVE AND THE NITROGEN EQUIVALENT PER ACRE OF 2,000,000 POUNDS OF SOIL.

Unit	Number Plants in Unit	Grams of NH_4NO_3	Pounds of N per Acre
1	5	0.000	0
2	5	0.142	20
3	5	0.284	40
4	5	0.710	100
5	5	1.420	200
6	5	2.840	400

Clermont silt loam was used as the medium for growth, principally because of its small content of organic matter. The air-dry soil was thoroughly mixed and sifted through a 36-mesh sieve to insure uniform composition. A definite amount of the silt loam, 5520 grams, was placed in each of thirty weighed jars after nitrogen in the form of ammonium nitrate had been thoroughly mixed with the soil of each unit except that of five check jars.* Table I gives data for the addition of nitrogen. An estimation of the amount of nitrogen absorbed by the seedlings during the first season showed it necessary to make a second similar application of ammonium nitrate in the spring of 1931.

The optimum moisture content of the soil was taken as 50 percent of the amount of water necessary for saturation,

*The term, "unit," will be used to designate any group of five jars having similar applications of nitrogen.

(Ref. in Emerson, 1925). After transplanting a weighed seedling to each jar, enough distilled water was added to give the desired moisture content.* While it was not possible to keep the moisture content of the soil constant, check weighings were made from time to time. Rapid evaporation from the soil surface was prevented by covering the top of each jar with a circle of paraffined cardboard.

The potted plants were arranged on tables in a greenhouse room where they remained during the two growing seasons. In order that the effects of the environmental factors might be equalized for all plants, the jars were frequently shifted on the tables. They were placed in cold storage from November 1, 1930, to March 15, 1931.

In an attempt to avoid any introduction of a non-nitrogenous base as a variable soil factor which might greatly influence the concentration of hydrogen ions, ammonium nitrate was used as the source of nitrogen. On May 25, 1930, the pH value of a soil solution from each unit was determined by means of a quinhydrone potentiometer. Following are the results:

Units	1	2	3	4	5	6
pH value............	4.88	4.88	4.64	4.55	4.44	4.44

Ten c. c. of distilled water and 10 grams of air-dry soil were thoroughly mixed to obtain a solution.

Total nitrogen determinations by the modified Kjeldahl method on the Clermont silt loam, before additional nitrogen was supplied, showed 600 pounds per acre.† Further total nitrogen determinations were made at the conclusion of the experiment on the soil of each unit, giving the following results:

Units	1	2	3	4	5	6
Pounds of N. per acre based on air-dry weight............	300	560	640	760	840	980

Ten gram samples in duplicate were used for each determination.

*All water used throughout the two growing seasons was distilled.

†All necessary corrections for the reagents were made in nitrogen determinations by the Kjeldahl method.

TABLE II.

MAXIMUM AND MINIMUM RANGES OF AIR TEMPERATURE AND RELATIVE AIR HUMIDITY INSIDE THE GREENHOUSE FOR GROWING SEASONS OF 1930 AND 1931.

TEMPERATURE.

1930	May	June	July	Aug.	Sept.	Oct.	Nov.
Range of max. temp.	60–105	70–102	82–107	70–105	66–92	59–93	83–101
Range of min. temp.	47–67	49–75	49–78	47–77	44–65	41–73	69–77
Max. range any one day	67–105	64–102	58–104	54–100	47–88	41–81	72–101
Min. range any one day	61–71	62–78	67–82	61–70	61–66	70–73	76–83

RELATIVE AIR HUMIDITY.

Range of max. hum.	52–89	69–95	61–95	61–95	79–95	52–94	41–61
Range of min. hum.	13–72	24–79	20–55	19–88	22–78	15–73	10–55
Max. range any one day	29–89	24–85	30–92	19–91	28–91	21–80	10–50
Min. range any one day	72–84	79–95	55–89	88–95	72–91	65–68	55–61

TEMPERATURE.

1931	Mar.	April	May	June	July	Aug.	Sept.
Range of max. temp.	73–96	66–101	66–99	85–105	88–106	73–105	75–108
Range of min. temp.	60–76	46–74	54–70	57–77	58–78	59–78	59–78
Max. range any one day	60–96	55–101	60–99	62–102	66–102	69–104	66–107
Min. range any one day	60–73	68–75	62–70	61–85	65–80	64–73	78–87

RELATIVE AIR HUMIDITY.

Range of max. hum.	50–77	45–96	50–90	70–90	69–87	69–90	80–89
Range of min. hum.	25–59	17–75	23–75	23–65	18–67	22–81	30–72
Max. range any one day	28–77	30–96	23–82	23–81	21–82	28–84	30–81
Min range any one day	49–51	75–80	75–84	81–89	67–87	81–89	72–89

During the course of the experiment, no attempt was made to control the atmospheric factors of the environment other than reducing the light intensity which otherwise had deliterious effects upon the seedlings on bright summer days. This was accomplished by coating the greenhouse glass with a lime-sodium chloride-water mixture not easily washed away by rain. Measurements of such major factors as air temperature, relative air humidity, and soil temperature were made, and relative light intensity was compared with that of full daylight.

Air temperature and relative air humidity (Table II) were recorded on charts by a hygro-thermograph which remained throughout both seasons near the center of the group of potted plants.

TABLE III.

MAXIMUM AND MINIMUM RANGES OF SOIL TEMPERATURE FOR GROWING SEASONS OF 1930 AND 1931.

	Temperature.						
1930	May	June	July	Aug.	Sept.	Oct.	Nov.
Range of max. temp.	56–88	60–87	68–89	70–88	61–88	56–80	68–81
Range of min. temp.	45–68	52–76	57–78	60–81	58–72	55–72	70–76
Max. range any one day	65–82	68–84	64–87	65–78	66–81	58–76	70–78
Min. range any one day	70–76	67–74	72–82	68–79	67–78	63–70	66–70

	Temperature.						
1931	May	June	July	Aug.	Sept.	Oct.	Nov.
Range of max. temp.	63–78	67–84	68–86	72–90	68–88	74–91	64–87
Range of min. temp.	63–72	58–70	57–69	62–78	65–80	68–79	66–81
Max. range any one day	68–82	62–84	73–82	69–85	73–87	70–86	68–83
Min. range any one day	73–78	64–73	68–74	75–87	72–80	69–77	67–78

The soil temperature (Table III), recorded by a soil thermograph, showed much more uniform diurnal changes and a much narrower range than the air temperature. The daily maximum temperature usually trailed the maximum air temperature approximately one to one and one-half hours, occurring from two-thirty to three-thirty o'clock in the afternoon.

The Eder-Hecht "Graukeil" photometer with Solio paper, was used to determine the total light intensity of the daylight period inside and outside the greenhouse for various periods throughout both seasons. In all instances, the photometers were loaded and placed in a horizontal position one night and read the following night. If the out-of-doors reading each time is assumed to be 100, at no time did any one of the simultaneous indoor readings fall outside the range, 83–92. The relation existing between the accumulative light intensity to which the seedlings were exposed and that of full daylight of a cloudy day did not vary from a similar relation on a clear day. These measurements are not intended to give the absolute intensities in both situations, but to show the relative intensity of light to which the seedlings were exposed as compared with that of full daylight.

Measurements of other environmental factors are not offered in an attempt to explain any correlation that may exist between them and the behavior of the plants, but as partial description of the conditions under which the seedlings were grown.

The plants were removed from the jars on September 15, 1931, the soil carefully washed from the roots and all necessary measurements made.

NITROGEN CONTENT OF PLANTS.

The analyses of the tulip poplar seedlings include both nitrate and total nitrogen determinations. These were made on the root, bark, and woody cylinder of plants of the original lot at the time of potting and of plants of each unit at the conclusion of the experiment and on the leaves of each unit at the end of each growing season, including leaves which fell during the period.

Methods.—The material from each part of the plants was weighed on analytical balances and dried to constant weight at 85° C. It was then transferred to weighed, ether extracted extraction thimbles, each loaded thimble weighed and extracted with 80 percent ethyl alcohol until the extract became clear, usually for a period of ten to twelve hours. The extracted loaded thimbles were dried in an 85° C. oven to constant weight. The extractions were made with Soxhlet extractors attached to water-jacketed condensers. Constant heat was applied by means of an electric hot plate.

The content of each thimble was at once finely ground in a food pulverizer and stored in a tightly stoppered vial. The extract was made up to volume, at 20° C., with 80 percent ethyl alcohol on the basis of one liter of extract for 50 grams of fresh material. The solution was kept in rubber stoppered Erlenmeyer flasks until analyses could be made.

Nitrate and total nitrogen, including nitrate nitrogen, determinations were made on the extracts. Aliquots of 100 c. c. of each alcoholic extract, placed in 800 c. c. Kjeldahl flasks, were evaporated down to 10 c. c. After the samples had cooled, 400 c. c. of distilled water was added. The solution was made slightly alkaline by the addition of a few drops of 50 percent sodium hydroxide. A small amount of Devarda's alloy was mixed with the contents of each flask to reduce any nitrate nitrogen present to ammoniacal nitrogen. The flasks were immediately connected with a still and distillation carried

TABLE IV.

PERCENT OF NITROGEN BASED ON BOTH FRESH AND DRY WEIGHT OF SEEDLINGS FROM ORIGINAL LOT.

PLANT PART	ON FRESH WEIGHT BASIS			ON DRY WEIGHT BASIS		
	Alcoholic Extract	Residue	Total N	Alcoholic Extract	Residue	Total N
Bark	0.09	0.58	0.67	0.18	1.22	1.40
Woody cylinder	0.08	0.14	0.22	0.16	0.26	0.42
Root	0.10	0.26	0.36	0.33	0.87	1.20

on slowly for an hour. The receiving flasks contained 50 c. c. of saturated solution of C. P. boric acid, approximately a 4 percent solution. As any ammonium was bubbled into the acid solution, ammonium borate was formed. This was then titrated with N/14 sulphuric acid. By simple calculations, the amount of nitrate nitrogen present was found.

Approximately 35 c. c. of concentrated sulphuric acid and 10 grams of a salt mixture of potassium sulphate, ferrous sulphate, and copper sulphate, in the proportion of 10 to 1 to 0.5, were added to the remaining content of each Kjeldahl flask and the whole placed over a gas flame until digestion of all organic matter was complete. After cooling, 400 c. c. of water was added to each flask and the content made decidedly aklaline with 50 percent sodium hydroxide. Distillation was again carried on for one hour. As for nitrate nitrogen, the receiving flasks contained 50 c. c. of a saturated solution of boric acid and after distillation titrated with N/14 sulphuric acid.

TABLE V.

PERCENT OF NITROGEN BASED ON BOTH FRESH AND DRY WEIGHT OF LEAVES OF 1930 GROWING SEASON AND OF ALL PLANT PARTS FOR 1931 SEASON.

Basis for Calculation of N Percent	Material Analyzed	Pounds of N Added per Acre per Year					
		0	20	40	100	200	400
Leaf, 1930.							
Fresh weight	Alcoholic extract	0.04	0.09	0.12	0.15	0.18	0.23
	Residue..........	0.10	0.12	0.13	0.14	0.17	0.18
	Total..........	0.14	0.21	0.25	0.29	0.35	0.41
Dry Weight	Alcoholic extract	0.05	0.11	0.15	0.18	0.23	0.29
	Residue..........	0.51	0.62	0.63	0.71	0.88	0.91
	Total..........	0.56	0.73	0.78	0.89	1.11	1.20
Leaf, 1931.							
Fresh Weight	Alcoholic extract	0.02	0.03	0.05	0.09	0.11	0.25
	Residue..........	0.28	0.37	0.41	0.56	0.65	0.90
	Total..........	0.30	0.40	0.46	0.65	0.76	1.13
Dry weight	Alcoholic extract	0.08	0.16	0.24	0.44	0.54	1.16
	Residue..........	0.95	1.36	1.45	2.11	2.35	3.89
	Total..........	1.03	1.52	1.69	2.55	2.89	5.05
Bark, 1931.							
Fresh weight	Alcoholic extract	0.03	0.04	0.06	0.07	0.16	0.20
	Residue..........	0.35	0.46	0.59	0.69	0.82	1.23
	Total..........	0.38	0.50	0.65	0.76	0.98	1.43
Dry Weight	Alcoholic extract	0.06	0.07	0.15	0.17	0.37	0.46
	Residue..........	0.61	0.83	1.10	1.25	1.47	2.06
	Total..........	0.67	0.90	1.25	1.42	1.84	2.52
Woody Cylinder, 1931.							
Fresh weight	Alcoholic extract	0.01	0.03	0.06	0.07	0.08	0.15
	Residue..........	0.21	0.24	0.32	0.32	0.33	0.37
	Total N........	0.22	0.27	0.38	0.39	0.41	0.52
Dry weight	Alcoholic extract	0.02	0.06	0.12	0.13	0.15	0.27
	Residue..........	0.39	0.40	0.53	0.54	0.55	0.61
	Total N........	0.41	0.46	0.65	0.67	0.70	0.88
Root, 1931.							
Fresh weight	Alcoholic extract	0.06	0.15	0.24	0.35	0.40	0.55
	Residue..........	0.24	0.39	0.51	0.64	0.81	0.98
	Total N........	0.30	0.54	0.75	0.99	1.21	1.53
Dry weight	Alcoholic extract	0.19	0.51	0.83	1.18	1.37	1.80
	Residue..........	0.61	0.89	1.23	1.70	2.11	2.55
	Total N........	0.80	1.40	2.06	2.88	3.48	4.35

Similar modifications of the Kjeldahl method were employed in determining the total nitrogen of the extracted residue as in the analysis of the extracts. Two gram samples of the residues were used.

Checks were run to detect any nitrogenous impurities in the reagents.

Results.—The results obtained from the analysis include in the extract those nitrogen compounds soluble in 80 percent ethyl alcohol and in the residue the nitrogen compounds insoluble in 80 percent ethyl alcohol. Each form is expressed in percent based on both fresh and dry weight of the plant part analyzed. Also, the total nitrogen, including nitrates, is shown for each of the plant parts in Tables IV and V. Since in no case was there enough nitrate nitrogen found to exceed the limit of experimental error, no further record has been made of these findings.

Figures 1, 2, 3, 4, and 5 show more clearly the relationship existing between the nitrogen content of the soil and the distribution of nitrogen in the seedlings.

Discussion.—Table V shows in detail the distribution of nitrogen in the seedlings. It may be observed that the percent of total nitrogen in the several parts of the plants analyzed increases with the increase of nitrogen in the soil medium. It may also be noted that the ratio between the percentage of total nitrogen in each plant part and that of its soil medium is not a constant one throughout the series. The nearest approach to a constant ratio occurs for the leaves of the 1931 season. While both the soluble and insoluble nitrogen in 80 percent ethyl alcohol increase with the soil nitrogen, the rate of increase of the latter is somewhat the smaller of the two in most cases. Total nitrogen, based on dry weight, was present in the greatest abundance in the leaf material and decreased in order in the root, bark, and woody cylinder. The woody cylinder was the only part which contained less than one percent of total nitrogen in all units, the alcohol soluble nitrogen being exceptionally small. The high percentage of nitrogen found in the leaves corresponds closely to the results of investigations by Ebermayer of various tree species.

If tulip poplar were a nitrate accumulating species, one would have expected an increase of nitrogen in the plant, corresponding to the increase of the element in the soil, but such did not occur. It is evident that a greater percentage of nitrogen was absorbed by plants of the units high in nitrogen than those containing a small amount; but analyses showed that, even though the nitrate nitrogen had entered the plant as such, it was transformed almost immediately into some other soluble form.

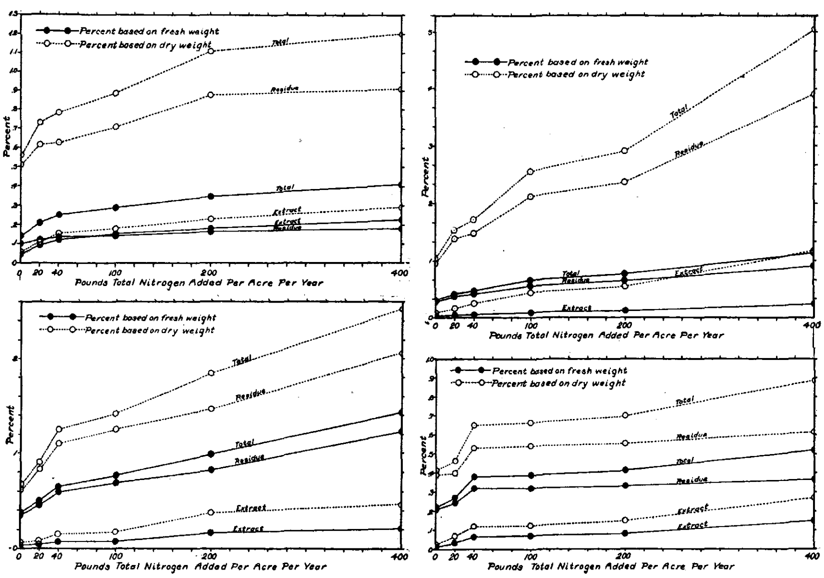
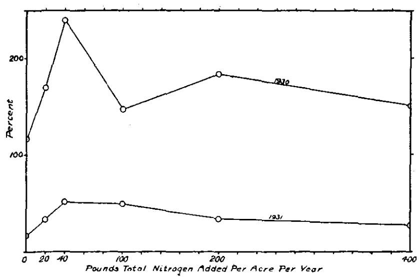


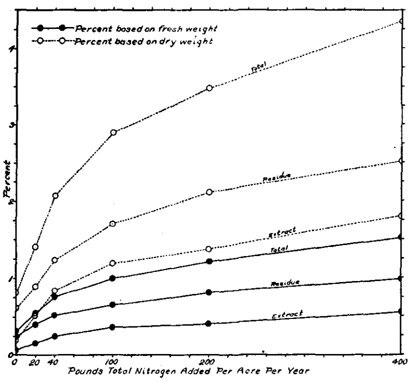
FIGURE 1. (*Upper left.*) Percentage of nitrogen, based on both fresh and dry weight, present in 1930 season leaves from the six units.
FIGURE 2. (*Upper right.*) Percentage of nitrogen, based on both fresh and dry weight, present in 1931 season leaves from the six units.
FIGURE 3. (*Lower left.*) Percentage of nitrogen, based on both fresh and dry weight, present in bark from the six units.
FIGURE 4. (*Lower right.*) Percentage of nitrogen, based on both fresh and dry weight, present in woody cylinder from the six units.

GROWTH RESPONSES.

Effects of Nitrogen on Leaf Color.—As early as the middle of July, 1930, very distinct differences in the green color of the leaves had developed in seedlings supplied with the varying amounts of nitrogen. This condition was quite noticeable throughout the remainder of the first season and all of the 1931 growing season. Leaves of the check plants were decidedly greenish-yellow. Those on the plants showing the higher growth rates contained the smaller quantity of chlorophyll.

Many of the mature leaves in the middle and upper parts of the crowns showed a browning of only the tips and persisted for several weeks, while some of the lower leaves became entirely brown and abscissed. The green pigment was somewhat better developed in the seedlings of unit two. All leaves of unit three except a few on one plant appeared much darker





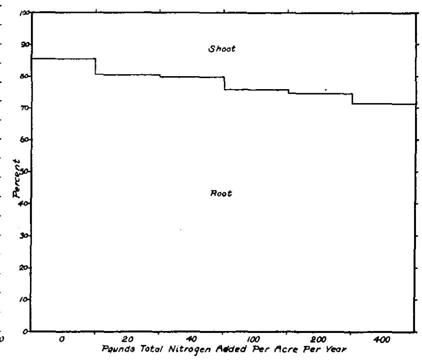


FIGURE 5. (*Lower left.*) Percentage of nitrogen, based on both fresh and dry weight, present in roots from the six units.

FIGURE 6. (*Upper.*) Relative percent increase in height of seedlings for growing seasons of 1930 and 1931.

FIGURE 7. (*Lower right.*) Percentage of shoot and root based on the total fresh weight of the individual units.

green in color. In units four and five, the leaves had a uniform dark green color; none of the lower ones showed browning. In the leaves of unit six, there appeared a blotching of yellow and green on the mature and overmature leaves. The latter soon turned brown and abscissed. Only the young leaves were free of the mottled effect.

It has been generally observed that a uniform yellowish-green color of leaf accompanies, in most plants, low available nitrogen, which limits the development of chlorophyll. The green and yellow mottled effect of leaves associated with an excess of available nitrogen is due to a decomposition of chlorophyll after the development of a dark-green color in the early

TABLE VI.

VARIOUS STAGES OF EACH SEEDLING IN THE BREAKING OF DORMANCY IN THE SPRING OF 1931.

Date of Observation	Condition of Plant	Pounds of N Added per Acre per Year																													
1931		0					20					40					100					200					400				
		Individual Plants																													
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
March 24	Buds swelling																														
	Buds bursting																														
	Leaves unfolding	x	x		x	x														x	x		x	x	x	x	x	x		x	x
	In full leaf																														
March 30	Buds swelling																x														
	Buds bursting						x	x		x				x		x		x	x			x									
	Leaves unfolding			x								x	x		x											x			x		
	In full leaf	x	x		x	x														x	x		x	x	x		x	x		x	x
April 5	Buds swelling																														
	Buds bursting								x																						
	Leaves unfolding							x		x				x		x	x	x	x												
	In full leaf	x	x	x	x	x	x				x	x	x		x					x	x	x	x	x	x	x	x	x	x	x	x
April 11	Buds swelling																														
	Buds bursting																														
	Leaves unfolding																														
	In full leaf	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

stages of growth. The concentration of nitrogen in the soil medium, at which mottling appears, depends upon the amount immediately available. Since nitrogen in the form of ammonium nitrate was at once available and there was no leaching from the jar, the toxic effect for tulip poplar appeared at a comparatively low concentration. The writer (1931) found mottling in white elm leaves grown under the same conditions as the mottled tulip poplar leaves.

Relative Dormancy.—Both the time at which dormancy began in the autumn and the time of breaking of dormancy in the spring were relatively earlier, the greater the concentration of nitrogen in the soil medium. As previously mentioned, lower leaves of the seedlings at the limits of the series were turning brown and abscissing as early as July 15; leaf fall continued from these plants until none remained on those in unit six by September 25. A week later, leaf fall for the seedlings of units one and two was complete. A few leaves still persisted, and many terminal buds showed active growth on the plants of units three, four, and five at the time of storage, November 15. Buds showing active growth in the late autumn were killed by the low temperatures during storage.

TABLE VII.

PERCENT INCREASE IN HEIGHT OF SEEDLINGS FOR GROWING SEASONS OF 1930 AND 1931, BASED ON HEIGHT AT BEGINNING OF EACH SEASON.

Average Percent Increase for Season	Pounds of N Added per Acre per Year					
	0	20	40	100	200	400
1930	117.7	169.8	241.4	147.0	184.6	151.0
1931	16.6	34.4	51.0	49.6	33.0	27.4

During the following spring, the plants of the series broke dormancy in the same order as dormancy began. Table VI shows the various stages of each seedling in the breaking of dormancy as observed at intervals of six days.

The time of beginning and breaking of dormancy of a species is of considerable ecological importance, and results for tulip poplar show that high and low available nitrogen favor an early beginning and early breaking of dormancy while intermediate quantities of available nitrogen favor a later beginning and a later breaking of dormancy.

Height Increase During Growing Season.—The increase in height of all plants was determined in centimeters for each of the growing seasons. The average increase for each unit was calculated and its percentage of the average original height of the seedlings in the unit found for the first season. The percent increase for the second season was based not on the average original height, but on the average height at the beginning of the second season. The results of the measurements are shown in Table VII.

To more clearly show the dissimilarity between the results of the two seasons' growth, they have been further recorded in graph form, Figure 6 (page 175).

It may be noted from Table VII and Figure 6 that, during the 1930 season, the seedlings did not show a height growth curve similar to that of the 1931 season. The irregularity is perhaps due to a "transplanting shock," principally a disturbance of the root systems. Wahlenberg, who tested the effects of various amounts of nitrogen on Engelmann spruce seedlings, found "Increases in growth were slight and, ... , were not in evidence until the second year, even though the fertilizer used was in readily soluble form. During its first year a tree seedling naturally expends much energy in root development at the expense of top growth. After having spent a year developing roots it seems better able to absorb nutrients and use them for further growth of the seedling as a whole, especially for top growth."

TABLE VIII.

AVERAGE PERCENTAGE OF INCREASE IN FRESH WEIGHT OF TULIP POPLAR SEEDLINGS OVER THE WEIGHT AT TIME OF POTTING.

	Pounds of N Added per Acre per Year					
	0	20	40	100	200	400
Average percent increase in weight...	132.5	263.8	356.8	432.2	317.4	260.8

Total Increase in Weight.—The total percent of increase of weight of the seedlings was based upon an average of the original weight of the one year old seedlings and final fresh weights for each unit. In either case, the plants were weighed without leaves, and the results in Table VIII do not include leaf weight. The combined leaf material for each unit for both seasons has a similar relation to the concentration of nitrogen in the soil as that of the plants as weighed.

Probably, the best indication of favorable conditions for growth of plants is the increase in weight. Table VIII shows that of the six media used the medium of unit four afforded these conditions. A close parallelism exists between data of Tables VII and VIII.

Shoot-to-Root Ratios.—At the conclusion of the investigation, the plants of each unit, carefully washed and dried with blotting paper, were cut into two parts, roots and shoots, and weighed separately. All fibrous roots broken in removing the plants from the soil medium were sifted out and included in the weights. Due to the decay and sluffing off of numerous small roots of plants of unit six, the shoot-root ratio for that group may be slightly too high. Figure 7 contains the shoot and root percentages based on the total fresh weights of the individual units.

TABLE IX.

AVERAGE SHOOT-ROOT RATIOS BASED ON FRESH WEIGHT FOR THE PLANTS OF EACH UNIT.

	POUNDS OF N ADDED PER ACRE PER YEAR					
	0	20	40	100	200	400
Shoot-root ratios.....	0.15	0.24	0.24	0.32	0.33	0.38

While the ratios of shoots to roots, Table IX, based on fresh weights are not necessarily indicative of the kinds or quantity of shoots and roots produced, they are an expression of the relative growth rates in the two organs. The fact that there existed a very small difference in the moisture content of similar tissues of plants grown in soil media with varying amounts of nitrogen makes the data more significant. This difference was much less than the difference in succulence of the seedlings indicated. It may be seen from the data, Figure 7 and Table IX, that the large shoot in proportion to the root is associated with a high amount of nitrogen in the soil and the small shoot in proportion to root with a deficiency of nitrogen.

SUMMARY.

The effects of various amounts of nitrogen on potted tulip poplar seedlings have been studied, and the following summary statements are based on plants grown only under the set of conditions described.

1. An insignificant amount of nitrate nitrogen accumulated in the tissues of tulip poplar seedlings regardless of the concentration of ammonium nitrate added to the soil medium.

2. Alcohol soluble nitrogen existed in much smaller quantities in plants of all units than did the alcohol insoluble nitrogen. While the rate of increase of both the soluble and insoluble nitrogen increased with the amount of the nitrate salt supplied, the rate of increase of the soluble form in the seedlings was much greater.

3. The total nitrogen, including nitrate nitrogen, was most abundant in the leaf and decreased in order in the root, bark, and woody cylinder.

4. (a) Leaves of plants supplied with little or no extra nitrogen had uniformly yellowish-green leaves.

(b) Leaves of plants supplied with additional nitrogen equivalent to 40, 100, and 200 pounds per acre had a uniformly dark-green color.

(c) Leaves of plants supplied with the highest amount of additional nitrogen developed at maturity a mottled green and yellow color.

5. Plants growing in the soil media having the highest and lowest concentrations of nitrogen began and broke dormancy relatively earlier than plants of the other units.

6. No definite correlation was noted between the height growth of the seedlings and the amount of the available nitrogen during the first season after transplanting. However, the greatest average height was attained during the second season by plants grown in soil media with nitrogen equivalents of 40 pounds and 100 pounds added per acre per year, the heights decreasing with greater and smaller amounts.

7. The greatest average weight of plants occurred with the addition of the equivalent of 100 pounds of nitrogen per acre, the average weights decreasing with the increase and decrease of nitrogen.

8. An increase of the shoot-root ratio was associated with the increase of the nitrogen supply.

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